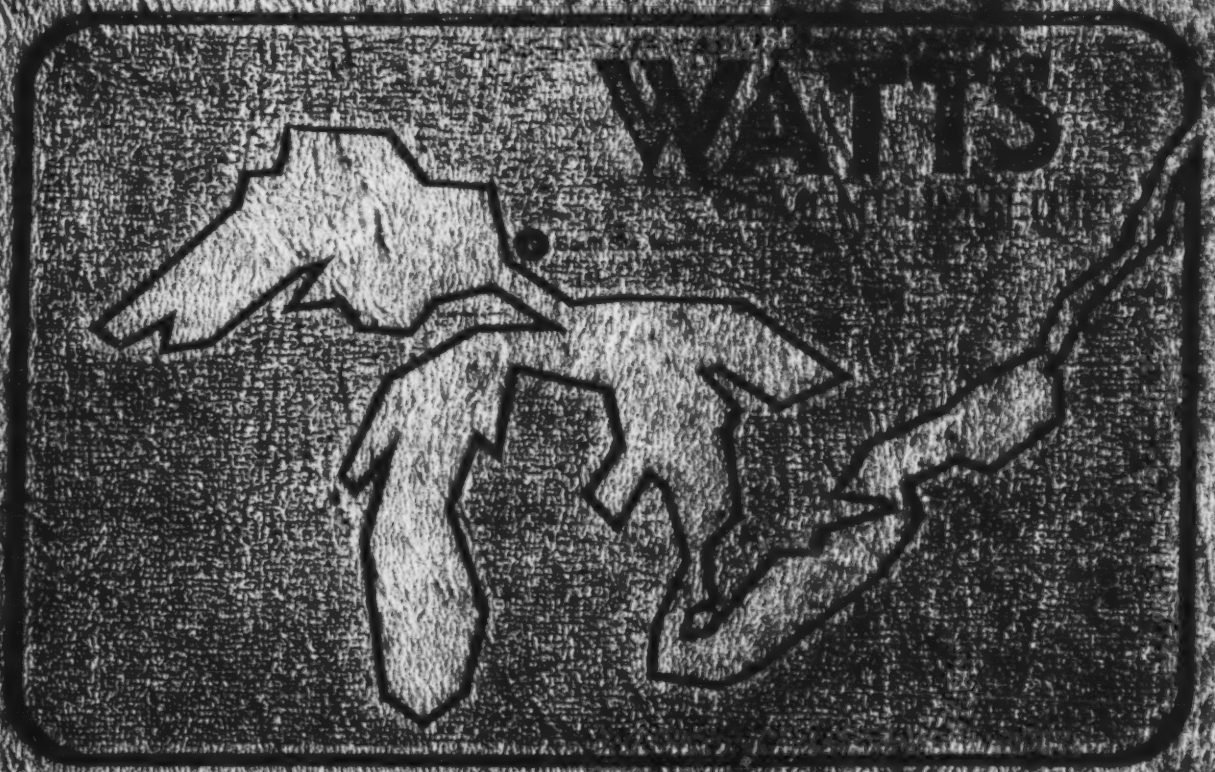
EVALUATION OF
ALGOMA STEEL BLAST FURNACE SLAG

SAMPLE PREPARATION



PREPARED BY

CANMET

DEPARTMENT OF ENERGY
MINES AND RESOURCES

CANADA

TITLE: EVALUATION OF BLAST FURNACE SLAG FROM ALGOMA STEEL CORPORATION'S #7 BLAST FURNACE FOR POSSIBLE USE AS AN ADDITIVE TO CONCRETE

- SAMPLE PREPARATION

FINAL REPORT

BY

WATTS CEMENT LTD.

WORK ON THIS PROJECT WAS CONDUCTED UNDER THE AUSPICES OF THE
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1.0.0 EXECUTIVE SUMMARY

A project was undertaken by WATTS Cement Ltd. of Sault Ste. Marie, Ontario, under the auspices of the Canada Center for Mineral and Energy Technology, Energy, Mines and Resources, Canada with the following objectives:

1. To prepare granulated slag samples from Algoma Steel's #7 blast furnace using a pilot version of a Paul Wurth granulation system.

2. To prepare slag cement samples from the granulated slag.

3. To obtain information regarding the grinding of granulated slag.

Upon installation of a pilot version of the Paul Wurth granulation system, approximately 460 metric tons of granulated slag were produced in four days of equipment operation. The granulated slag had the appearance of light brown sand with particles of consistent size. Installing and operating the granulation equipment demonstrated that a full-sized granulator would not disrupt the operation of Algoma Steel's #7 blast furnace.

Granulated slag was ground into cement at St. Lawrence Cement's Clarkson plant. Although blaine finenesses of 3000, 4000, 5000 and 6000 were targeted, the physical limitations of the grinding circuit restricted

the nominal finenesses of the ultimate sample to 3400, 3800, 4400 and 4800. Slag cement ground to 3400 and 4400 blaine had to be reground in a pilot scale mill by Witteck Development Inc. to obtain a sample of 5800 blaine in fineness. All slag was eventually distributed to laboratories for concrete testing and evaluation for possible use as a mine backfill binding agent.

The ground slag was off white, lighter in colour than both Portland cement and slag cement made from pelletized slag. Unit power consumption values for grinding granulated slag were similar to values typical for clinker in the lower blaine range (3000 to 4500), but higher than clinker at higher blaines.

2.0.0' INTRODUCTION

The purpose of this report is to present the findings of the project conducted to provide granulated slag samples and ground granulated slag samples for testing by others. The report is organized into three sections, one describing the preparation of the granulated slag samples, one describing the preparation of the ground granulated slag samples and the other presenting the conclusions drawn from the results of the project. A series of photographs is also included as Appendix 1 providing a visual record of the major activities of the project as it progressed.

The project was managed by WATTS Cement Ltd. of Sault Ste. Marie under the auspices of the Canada Center for Mineral and Energy Technology, Energy, Mines, and Resources, Canada.

3.0.0 SLAG GRANULATION

3.1.0 EQUIPMENT DESIGN & INSTALLATION

3.1.1 Selection of the Granulation System

Granulation was selected as the method of obtaining quenched slag samples because at the time when installation of a pilot plant was being considered, current plans were to install a full-sized granulation system for processing 100% of the slag from Algoma Steel's #7 blast furnace. A granulation system, using rotary filter dewatering, was established as the most suitable method of producing cementitious hydraulic slag at Algoma on the basis of end product quality, capital costs, operating costs, pollution control and flexibility. The three established methods of slag quenching which were considered for installation at Algoma were:

1. Granulation - Rotary Filter Dewatering (Paul Wurth, Luxembourg)

2. Granulation - Filter Bed Dewatering (Rasa, Japan, Paul Wurth, Luxembourg)

3. Pelletizing - (National Slag, Canada, Sheridan Corporation, U.S.A.)

Paul Wurth Ltd. had designed a pilot unit for a blast furnace at a steel mill in the United States and on the basis of their experience,

indicated willingness to design a suitable unit for Algoma Steel. The flexibility of the granulation system provided the opportunity to install and operate a pilot plant at a reasonable cost.

3.1.2 The Slag Granulation Process

In the granulation system, the molten slag is quenched very rapidly by jets of high pressure water. The quenched slag, with the aid of excess water, then flows by gravity through the cold runner to a dewatering system. Rather than incurring the cost of installing a mechanical dewatering system with the pilot plant, it was decided to allow the quenched slag to flow from the cold runner directly into an existing slag pit and allow excess water to drain into nearby sewers. Quenching water is proportioned to the estimated flow of the slag in accordance with the quenching rate required to produce a suitable percentage of amorphous slag (glass content).

3.1.3 Designing the Pilot Plant

The most important factors taken into account during the pilot plant design phase were the need for quality samples, site conditions, the blast furnace operating schedule, cost and safety. Paul Wurth Ltd. was responsible for the design of the pilot unit, but close contact was maintained with blast furnace operating and maintenance personnel to ensure equipment design parameters were appropriate. Fabrication and erection contractors were asked to assess site conditions and evaluate

structural support designs with emphasis on an expeditious and safe equipment installation.

The most important design criteria was that the unit had to provide a quality sample, representative of the quenched slag produced by a full-sized granulator, with the key process variables being the temperature of the molten slag as it arrived at the granulation head, and the flow rate of the quenching water relative to the flow rate of the slag. Paul Wurth had found that the chances of producing granulated slag with a suitable glass content increased as the temperature of the molten slag entering the granulation head became higher, and also as the rate of quenching became higher. Convective heat losses as the molten slag flows from the furnace to the granulation unit in the open trough cause the slag temperature to fall. These heat losses had to be maintained at the levels expected when the full sized plant is in operation to generate a representative slag sample. Since less than 100% of the molten slag would be granulated the slag flow had to be split into two streams, somewhere upstream of the granulation head. To keep the surface area through which convective heat losses would occur the same as it would be for the full-sized plant, the slag flow was divided directly adjacent to the granulation head using a flow control orifice and a removable sand dam. The hot runner extension had one branch which would carry slag through the flow control orifice to the granulation head, one branch which would carry the excess slag to the north slag pit (granulated slag was deposited in the south slag pit - see Exhibit 1) and another branch which would be used in the event slag had to be flushed through the granulation unit when it was not operating. By splitting the slag flow at a location directly adjacent

to the granulation head, molten slag would be delivered to the granulation head at a temperature close to that expected with the full sized unit because the molten slag surface area through which convective heat loss would occur during granulation would be the same in both cases. The flow control orifice was sized by Paul Wurth to match the design flow of the pumps which would supply water to the granulation head, and provided the optimum quenching water flow to slag flow ratio.

The pilot granulation unit was an extension of the existing slag runner system and had to be tailored to current blast furnace site conditions. The problem of having the support structure for the granulation unit erected within the containment area into which molten slag is flushed was overcome by erecting an embankment which provided a bearing surface for equipment supports above the highest evaluation reached by the molten slag. An earlier plan involved construction of a temporary dyke to provide protection from molten slag for pile driven support columns but careful analysis of costs and potential problems suggested an embankment erection was the best alternative. The embankment elevated the granulation unit approximately twelve feet above the slag pit floor, minimizing the risk of having the front-end loader, which clears the pits of air cooled slag, or one of the large Terex trucks accidently contact and damage the supports, and isolating the equipment from the molten slag in the slag pit. This elevated design allowed the normal pit cleaning operations to continue in the presence of the granulation equipment.

The pilot unit was designed to be installed very quickly because the blast furnace operating schedule is not flexible, and provides few

occasions suitable for working in the slag pit area. The slag pit area becomes available for approximately ten hours on maintenance days, typically once per month. The unit was designed to be installed within one maintenance day by providing for prefabrication of several component pieces and assembly of these components in the field. The component pieces were the hot runner, the cold runner, the piping and the support structure.

Precautions were taken to ensure the safety of all Algoma Steel and WATTS Cement employees during granulator operation. Platforms, railings and footplates were all designed for the equipment to conform to or exceed the requirements of the Occupational Health and Safety Act. Factors of safety were incorporated into the design calculation for all support structure members.

3.1.4 Fabrication and Installation

The main constraint for planning the fabrication and installation of the pilot granulator was the blast furnace operating schedule because the amount of time available for field work was restricted. Algoma Steel's #7 blast furnace typically generates slag for 45 to 60 minutes approximately 10 times every 24 hours with maintenance periods being the only interruption to this cycle. The granulation equipment was installed in component pieces during a maintenance period to prevent any interference with the operation of the blast furnace and also to minimize the safety hazards associated with working in the slag pit area when slag was being discharged from the furnace. The component pieces

which made up the pilot unit were fabricated and installed by Conaquip Ltd., a Sault Ste. Marie construction contractor. The pieces were partially assembled at Conaquip's local shop and delivered on flat bed tractor trailers to Algoma Steel where they were unloaded using a large hoist, then welded and bolted into place.

3.2.0 PILOT PLANT OPERATION

3.2.1 Operating Plans

The operation of the granulator had to be planned around the pit cleaning schedule of the blast furnace slag cooling pit. Plans were made to operate the granulator between the time when Algoma Contractors had finished removing the air cooled slag from the south slag pit and when Algoma Steel had stopped flushing slag from the north cast house of #7 blast furnace into the north slag pit and began flushing from the south cast house to the south pit. This cast house reversal normally occurrs every two days at approximately 7:00 p.m. and Algoma Contractors generally remove air cooled slag from the south pit on the day shift (7:00 a.m. to 3:00 p.m.) of pit reversal day. To provide more time for slag granulation and granulated slag recovery from the bottom of the pit special arrangements were made to have the south pit cleaned on the night shift (11:00 p.m. to 7:00 a.m.) prior to pit reversal day. This schedule provided approximately 12 hours for operating the granulator, recovering the granulated slag and preparing the south slag pit for the cast house reversal.

3.2.2 Commissioning Phase

The objectives of the commissioning phase were to verify the operational integrity of the equipment and site, and familiarize operating personnel with the operation of the equipment. Commissioning phase activities included meetings, site and equipment inspections and quenching water system trial runs.

Activating the quenching water supply without molten slag in the system provided the opportunity to verify the integrity of the piping including all valves and connections, ensure the capacity of the slag pit drainage system was sufficient to remove the excess water from the slag pit floor, and give the operators experience with the system start up routine and a convenient occasion to discuss general operating plans. Once the piping proved to be sound, the valve settings for the appropriate quenching water flow rate were noted and marked. Equipment operators came to the project with prior blast furnace operating experience and helped establish the procedure for controlling the slag flow upon seeing the design of the hot runner extension. During the quenching water trial, the operators gathered the tools, materials and safety equipment they would need for their work and met with the supervisory personnel they would be interacting with.

3.2.3 Operation

The granulator operation was cyclical, the components of the cycle being activities related to preparing the equipment for the next cast or an extended shut-down and activities required during a cast. The time from the end of one cast to the time when slag started to flow again was typically two hours, with slag flow lasting approximately 45 to 60 minutes. All tasks relating to the operation and maintenance of the granulator were the responsibility of the WATTS Cement operators.

Activities relating to preparing the granulation equipment for the next cast included removing residual air cooled slag from runner troughs, removing iron from the iron trap, repairing the refractory lining of the hot runner extension, preparing refractory dams, activating the quenching water and inspecting the operating tools. Residual air cooled slag was removed from the slag troughs between each cast to prevent any free pieces from clogging the flow control orifice just upstream of the granulation head. An iron trap was built into the hot runner extension to keep the granulated slag free of iron. Pieces of iron were removed from the trap after each cast. Removing the residual air cooled slag and iron as well as erosion from the molten slag flow contributed to the need to inspect and repair the refractory lining of the hot runner. The purpose of the refractory dams were to divert and control the flow of the molten slag and with the exception of the dam located just upstream from the granulation head containing the flow control orifice, were made from a mixture of sand and refractory material. The flow control orifice dam was made from 100% refractory to provide more structural

stability for the orifice than would be provided by sand alone. Also, the additional stability was necessary because the orifice dam was subjected to the velocity pressure of the molten slag flowing into the hot runner. Quenching water was activated several minutes before slag was expected to provide time for fine tuning the flow rate and to verify operation of the supply pumps.

Technical representatives from Paul Wurth witnessed the initial granulation run and drew on their experience with granulation to guide the equipment operators through the process of fine tuning of the quenching water flow rate. The quenching water flow was changed to suit the actual slag flow based on visual inspection because there was no accurate way to measure the actual slag flow through the orifice, and no flow meter in the water line. Once a suitable flow rate had been established, valve settings were marked and repeated on successive granulation runs.

Activity during granulator operation was limited to controlling the level of the refractory dam in the bypass runner as required to regulate the amount of slag flowing to the granulation head. The top layer of this dam was made of sand and trimmed using a long probing bar to lower the flow rate of the slag flowing to the granulation head if the ratio of quenching water to molten slag went below minimum levels. The criteria for trimming the bypass runner dam was the granulated slag cold runner discharge temperature, as measured by the colour of the slag as it flowed from the cold runner. If the slag had more than a very dull red glow, it was decided that not enough cooling had taken place, and the bypass dam was trimmed to reduce the flow of slag to the granulation

head. Just prior to the end of the slag flow, the bypass runner dam was destroyed to provide for drainage of the hot runners, and facilitate easy cleaning in preparation for the next cast.

For extended shutdowns, all quenching water supply lines were drained, runners were cleared of air cooled slag and iron, and the granulation unit was covered to protect the refractory lining from the weather. Restarting the granulator after an extended shutdown was performed by carrying out the normal activities related to preparing the equipment for a cast.

3.2.4 Granulated Slag Handling and Storage

The three steps of the slag handling process were allowing the excess water to drain from the slag, removal of the slag from the pit to a temporary storage area on Algoma's property, and shipment of the slag to St. Lawrence Cement in Mississauga. Water removal and slag handling in the area of the granulator are automatic with a full-sized granulator but were not included with the pilot plant in the interest of minimizing capital cost.

Granulated slag from all casts on the day when the pilot plant was operated was accummulated in the south slag pit and excess water was allowed to drain off through the existing sump system prior to recovering the slag and transporting it to the temporary holding area. The water drained from the granulated slag very quickly and formed a large pool adjacent to the granulated slag pile forcing the slag pit

sump system to work at its capacity. The size of the pool diminished enough for the removal operation to begin approximately one and one half hours after the end of the final granulation run of the day.

Granulated slag was recovered with a front end loader and haulage vehicles just prior to pit reversal. The front end loader scooped the granulated slag from the pit floor, being careful to avoid residual air cooled slag, and loaded a haulage vehicle which removed the slag to a temporary holding area. The slag remained in the temporary holding area for several days, providing time for more drying, before being loaded into covered highway vehicles for transportation to the grnding facility in Mississauga.

The original plan to recover the granulated slag directly into a dump truck parked under the cold runner was abandoned to eliminate the risk of damaging the truck. The high velocity of the water/steam/granulated slag slurry flowing from the cold runner would damage the box of a truck parked directly below the chute. After witnessing a trial run, the trucking firm owner rejected the plan to have one of his vehicles in the slag pit when the granulator was operating.

3.3.0 SUMMARY OF GRANULATION RESULTS

The pilot granulation unit was operated on four different days and approximately 460 metric tonnes (Mg) of granulated slag were produced. The granulated slag had the appearance of sand, light brown in colour and was composed of particles of consistent size.

A detailed summary of the results of the pilot plant operation appears in Exhibit 2.

A small quantity of air cooled slag, less than 4% by weight, was mixed into the granulated slag sample. The contamination resulted from the impact of the granulated slag and water on the slag pit floor stirring the existing air cooled slag into the granulated, and also from the front end loader inadvertently scooping parts of the pit floor into the sample.

4.0.0 SLAG GRINDING

4.1.0 GRINDING AT ST. LAWRENCE CEMENT LTD.

4.1.1 Material Handling

A total of 242.2 Mg of granulated slag from the Algoma plant in Sault Ste. Marie was trucked to the St. Lawrence plant. The moisture content of the slag received was approximately 8%.

The material was first brought to the central storage hall in the plant. This hall is served by an overhead travelling clamshell type crane. The loads were dumped onto a previously cleaned spot on the floor of the hall and then transferred to a steel bottom bin (also previously cleaned) using the clamshell crane. This bin held all of the granulated slag received except the last truck load. The sample was stored in the bin to minimize the potential for contamination with dust emissions from other materials. Material flow through the cement plant is shown schematically in Exhibit 3.

4.1.2 Drying

St. Lawrence had advised that drying would be necessary before grinding could take place in their mill. In their experience, grinding a slag with more than 4% moisture had affected the quality of the ground product. Two methods of drying were considered. The first was to lay

the material on the concrete floor beneath #1 kiln and then turn it over occasionally with a front end loader. The second was to use the converted kiln which is now used as a dryer. The first method, although simpler, had the problem of taking more time and could expose the sample to more contamination. In addition, kiln #1 was not to be in operation until the week of December 3, and further delays were not acceptable. On the basis of these considerations, it was decided to dry the granulated slag in the converted kiln. To eliminate any chance of contamination by clinker dust from the exhaust gases normally used for drying, a temporary oil burner was used as a source of heat.

Prior to drying the granulated slag, about 100 Mg of other slag material from the St. Lawrence Cement inventory was passed through the dryer, without heat, to flush out the system. Further, approximately 30 Mg of the Algoma slag that went through the dryer was wasted at the beginning of the run to ensure a proper cleaning of the system.

As it became apparent that there was more air cooled slag in the sample than initially anticipated a four person crew was stationed at the dryer feed conveyor to separate the air cooled slag lumps. Approximately 5 Mg of air cooled material was picked off before going into the kiln-dryer.

The moisture of the slag fed to the dryer was less than 6%. The dryed slag contained less than 0.3% moisture.

4.1.3 Description of St. Lawrence Cement Grinding Equipment

The #4 clinker grinding mill was used. Exhibit 4 shows design information on the mill, separator and ball charge. This mill was being used for clinker grinding and had a ball charge suited for that purpose. Resizing and changing the ball charge was ruled out on the basis of high costs and scheduling problems. At the time, St. Lawrence expressed their doubts that changing the ball would have a noticeable impact on efficiency or end product quality. It was also considered that the increase in efficiency, according to St. Lawrence experience, was rather small.

The grinding circuit was cleared of contaminants by flushing it through with the same 30 Mg of granulated slag which was used to flush the dryer.

4.1.4 Grinding at St. Lawrence

Two persons were stationed at the mill weighfeeder to discard any remaining air cooled slag and foreign matter. Approximately 1 Mg of material was collected. At the same time a sample was scooped every half hour to form a composite sample of material fed to the mill. Laboratory testings indicated that less than 2% by weight of air cooled slag and foreign matter were retained on a #4 screen (~1/4").

The original grinding plan was to produce the highest blaine (6000) first. However, after three hours of trying with a feed rate as low as

3 Mg/h it became apparent that the mill and separator were not properly loaded and were not behaving in the normal way. A nominal 4000 Blaine sample was collected into the waiting truck tanker under these conditions.

As soon as the mill feed rate was increased above 6 Mg/h the mill and separator started to load correctly and normal patterns returned, i.e. increasing feed rate decreases Blaine achieved. A second nominal 4000 Blaine sample was then sent to a second waiting truck. As the loading was increased further and the separator blades were adjusted the nominal 3000 blaine sample was obtained fairly easily. At this point it was decided to reduce feed rate and try for higher Blaine samples. A sample close to 4800 Blaine was then obtained. However, further reduction of feed would not produce a higher blaine and so the 6000 Blaine sample was not obtained.

The ground slag was an off white color, lighter than both portland and ground pelletized slag. The results of the color tester (Exhibit 5) verifies this visual observation.

On the basis of these results, there are doubts about obtaining a 6000 Blaine sample with the mill system used, even if a more suitable ball charge is used. A more efficient system may be required. Current slag grinding installations that have achieved this fineness level have more efficient separators (cyclone type) and more efficient mills (higher L/D ratios, classifying liners, etc.).

4.1.5 Packing

As the targeted Blaine was reached a diverter gate was switched to put the ground material into a waiting cement truck tanker. This gate was installed by St. Lawrence Cement just ahead of the bucket elevator at the cement storage silos. From here the material was blown through a flexible rubber hose to the bagging machine hopper using the truck's own compressor. A temporary alleviator tank was installed by St. Lawrence on the floor above the hopper to relieve the compressed air through a connection to a dust collector. The hopper was drained completely between fillings with samples of different Blaine. Bag weight varied from 39 to 40 kg. See Exhibit 6 for a summary of the sample data and quantities produced.

The bags were stacked on pallets (maximum 40 to a pallet) and then stored under the kiln-dryer in the kiln building.

Slag cement was distributed to mines who expressed interest in testing the material for possible use as backfill binder, to CANMET laboratories in Ottawa, to an independent testing laboratory and to the Ontario Research Foundation. Distribution quantities are shown in Exhibit 7.

4.1.6 Sample fineness

Each sample run was assigned a nominal Blaine number which corresponded to the target figure. Samples were taken at the separator product discharge and tested for fineness for control purposes during the grinding. A composite sample for the run was collected on the discharge belt to the packing area. Exhibit 6 shows a summary of the Blaine figures obtained from the control samples (at mill) and from the run sample (composite).

Exhibit 8 shows the particle size distribution for the four samples bagged. This testing was done by St. Lawrence personnel using a Microtrac machine. A typical particle size distribution for type 10 portland cement is presented for comparison (Exhibit 9).

4.1.7 Unit Power Consumption

Approximated unit power consumption figures for grinding were obtained by dividing the mill motor power demand by the approximate feed rate. Exhibit 10 shows the relationship between unit power used per Mg of product as a function of the fineness of the grind.

The grinding balls in the mill used were sized for optimum efficiency when grinding clinker. However, since the granulated slag is considerably finer it is expected that resizing the grinding balls would have resulted in an increased throughput, thus decreasing the energy

used per ton. St. Lawrence's previous experience with a ball charge such as the one shown in Exhibit 4 resulted in an increase in throughput from 13.5 to 15.0 Mg/h at 4400 Blaine. The unit power figures shown in Exhibit 6 have been corrected to reflect the increased efficiency that would be achieved when using a properly sized ball charge.

The curve in Exhibit 10 seems to indicate that the unit power consumption values for grinding granulated slag are similar to typical figures for clinker in the lower Blaine range (3000 to 4500). At higher Blaine, however, the granulated slag seems to require more power for grinding than clinker.

4.2.0 GRINDING AT WITTECK DEVELOPMENT INC.

4.2.1 The Need for Regrinding

Slag cement regrinding was necessary because St. Lawrence Cement Ltd. did not produce samples of the desired Blaine finenesses. The original plan was to produce samples of 3000, 4000, 5000, and 6000 Blaine, but as it happened, the granulated slag was more difficult to grind than expected and the actual cement finenesses ended up at 3400, 3800, 4400, and 4800 cm2/g. After reviewing the the results of the St. Lawrence grinding and considering the low chance of obtaining a product sample within 200 Blaine units of a target fineness, it was decided to designate the 3800 Blaine sample as nominal 4000, the 4800 Blaine sample as 5000, and regrind the remaining 3400 and 4400 Blaine samples with the objective of obtaining a product sample of at least 5800 Blaine, which

would be accepted as nominal 6000 Blaine. It was decided that regrinding 3400 and 4400 Blaine material would be more economical than using granulated slag as the raw material because the reduced grinding time associated with preground material meant lower energy consumption and less operating labour, translating into lower grinding mill operating costs.

The regrinding work was done at Witteck Development Inc., an independent research and development firm, in a pilot scale dry grinding mill. The mill circuit is shown in Exhibit 11. Ground material was collected in varying Blaine conditions from the classifier discharge, the cyclone discharge and from the baghouse, using 45 gallon drums and identified as to whether the feed material had been preground to 3400 or 4400 Blaine. It was then determined by trial and error that mixing an equal proportion of the material from each drum containing ground product having 4400 Blaine preground slag cement as the feed material resulted in a material with a composite Blaine of 5800. Blending was then done in a small rotating mixing drum, to ensure the slag cement was thoroughly mixed.

4.3.0 SUMMARY OF GRINDING RESULTS

A summary of the slag cement sample preparation quantities appears in table #1 below:

Table #1 - Slag Cement Sample Quantities

Blaine	Quantity Recovered (kg)	Sent to WDI for Regrinding (kg)	Final Quantities (kg)
3400	2,808	1,677	1,131
3800	3,744		3,744
4400	10,530	9,009	1,521
4800	4,290		4,290
5500			1,400
5800			4,637

5.0.0 CONCLUSIONS

5.1.0 GRANULATION

The operation of the pilot granulation was successful and leads to the following conclusions.

1. The granulated slag produced by the granulation unit was representative of the granulated slag which would be produced by a full sized granulator installed at Algoma Steel.

2. A full sized granulator would not interfere with the normal operation of Algoma Steel's #7 blast furnace.

5.2.0 GRINDING

The following conclusions are qualified by noting they have been made on a very small amount of information. Many more tons of slag must be ground to prove the results of the sample grinding runs are representative. The conclusions regarding grinding energy should be qualified to take into account the fact that the the ball charge in the grinding mill at St. Lawrence Cement was designed for clinker, not granulated slag.

1. It is possible to grind granulated slag in a conventional ball mill.

2. It is possible to grind granulated slag to a variety of finenesses as measured by the Blaine method

3. Unit power consumption values for grinding granulated slag are similar to those for grinding clinker in the lower blaine ranges (3000 to 4500).

EXHIBITS

EXHIBIT 1
EVALUATION OF BLAST FURNACE SLAG
LAYOUT OF #7 BLAST FURNACE RUNNER SYSTEM - PLAN VIEW

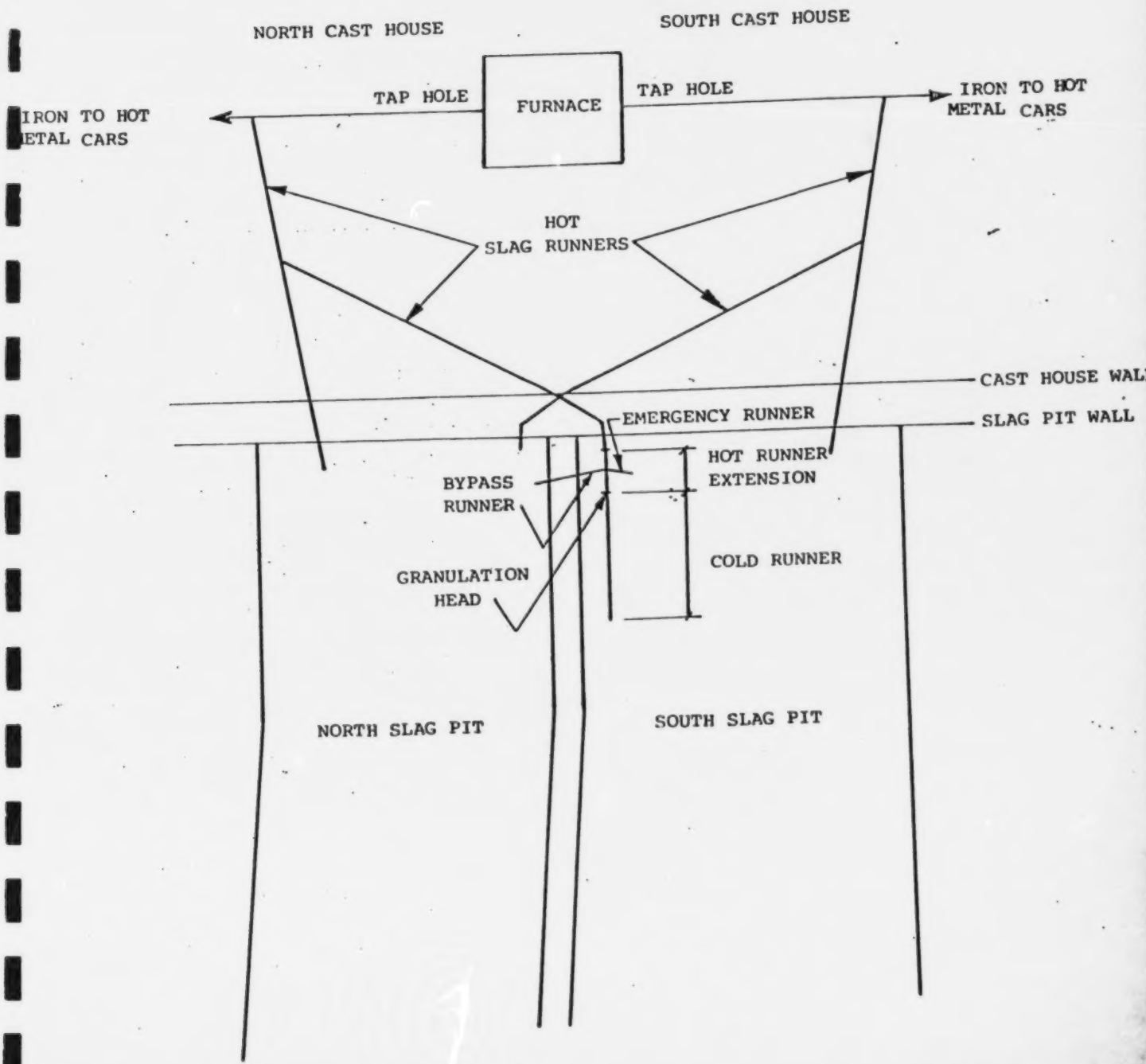


EXHIBIT 2
Evaluation of Blast Furnace Slag
Granulated Slag Production

Date of Granulation	Number of Casts	Granulated Slag Produced (metric tons)	Average Tons per Cast (metric tons)
November 14, 1984	4	182	45.5
November 19, 1984	3	144	48.0
November 23, 1984	2	133	66.5
November 29, 1984	2	128	64.0

Granulated Slag Particle Distribution *

Microns	% Passing
4750	100.0
2360	99.2
1180	78.3
600	36.5
300	8.1
150	2.2
75	0.7

* By Wright and Barker Laboratory - Sault Ste. Marie

EXHIBIT 3
EVALUATION OF BLAST FURNACE SLAG
SLAG DRYING AND GRINDING SCHEMATIC

EXHIBIT 4
Evaluation of Blast Furnace Slag
St. Lawrence Cement Clarkson Plant
-Grinding Mill System # 4

1.0 MILL

-Supplier: Allis Chalmers
-Diameter: 3.0 meters
-Length: 8.4 meters
-Drive: 1000 kW motor
-1st compartment: 3.0 meters long
-2nd compartment: 5.4 meters long
-Ball Charge: 32%

2.0 BALL CHARGE

Compartment	Ball Charge A(2)		Ball Charge B(3)	
	Mg	Size	Mg	Size
1	10.5	90	8.5	70
	8.0	80	11.0	60
	8.0	80	7.0	50
2	16.0	50	16.0	50
	22.0	40	22.0	40
	20.0	30	20.0	30

3.0 SEPARATOR

Supplier: Sturtevant Mill Company
Size: 4.9 meters (16 feet)
Controls: Fixed Speed Drive

Notes:

1. The size of ball charge is the nominal diameter of the balls in millimeters.

2. The ball charge currently used for clinker and for the Algoma slag

3. The ball charge used by St. Lawrence on slag material from another source

EXHIBIT 5
EVALUATION OF BLAST FURNACE SLAG
WHITENESS OF GRANULATED SLAG CEMENT - RESULTS OF REFLECTION METER TEST

Material	Relative Reflection
WATTS Slag - Lab Ground	68.0
WATTS Slag - Mill Ground	54.5
St. Lawrence Slag	44.0
St. Lawrence Portland	40.0

The reflection meter provides a relative indication of whiteness in no particular units. A higher relative reflection indicates a whiter cement.

EXHIBIT 6
Evaluation of Blast Furnace Slag
Summary of Grinding Data from Nov. 30, 1984 Test Grind

SAMPLE CODE NUMBER	BLAINE (1)		SAMPLE COLLECTED		MILL FEED RATE		APPROXIMATE POWER CONSUMPTION kWh/Mg
	AT MILL	COMPO-SITE	BAGS	kg	Mg/h ACTUAL	(2) COR'TD	
3000	3574 3410 3367	3260	72	2808	19	21.1	39.6
4000-1	3807 3788 3955 3593 3237	3732	96	3744	37	3.37	278.37 (3)
X (4)	3863 3955	NONE	NONE	NONE	16	17.8	47.0
4000-2	4352 4382 4382	4353	270	10530	10	11.1	75.2
5000	4732 4732 4732	4656	110	4290	6 ?	6.7 ?	125.4 ?(3)

NOTES:

1. Specific gravity of 2.89 used in the calculation of the Blaine.
2. Figures adjusted to compensate for an unfavourable ballcharge.
3. Feed rate and unit power consumption not representative due to mill underloading.
4. Sample not collected.

EXHIBIT 7
Evaluation of Blast Furnace Slag
Slag Cement Sample Distribution

DESTINATION	QUANTITIES - BY BLAINE (39 kg bags)			
Blaine ->	3400	3800	4400	4800
Sample Code ->	3000	4000-2	4000-2	5000
CANMET (Ottawa)	55	96	233	78
INCO (Sudbury)	0	0	10	5
Falconbridge (Sudbury)	0	0	0	0
Kidd Creek (Timmins)	0	0	5	5
Noranda - GECO (Manitouwadge)	0	0	5	5
Geocon (Sudbury)	16	0	16	16
Ontario Research Foundation (Mississauga)	1	0	1	1
TOTAL SHIPPED ->	72	96	270	110

EXHIBIT 8
Evaluation of Blast Furnace Slag
Particle Size Distribution of November 30, 1984 Grind

SIZING	COMPOSITE BLAINE			
	3260	3732	4353	4656
176	100.0	100.0	100.0	100.0
125	100.0	100.0	97.5	99.3
88	95.5	99.5	96.2	99.3
62	89.3	98.3	90.5	88.9
44	87.9	96.0	87.1	88.7
31	72.5	80.9	78.8	88.7
22	59.8	66.3	77.2	81.4
16	51.3	62.8	74.2	80.5
11	45.3	59.6	67.6	80.5
7.8	39.5	50.6	64.9	60.6
5.5	22.7	31.1	42.2	32.0
3.9	11.4	16.1	21.3	22.6
2.8	4.8	6.3	8.3	10.4

NOTES:

1. Results show cumulative percentage passing.

2. Sizing is in microns (um).

EXHIBIT 9
Evaluation of Blast Furnace Slag
Typical Particle Size Distribution for Portland Cement *

SIZING (microns)	% PASSING
176	100.0
125	98.5
88	96.8
62	90.5
44	77.0
31	67.0
22	52.3
16	39.7
11	31.2
7.8	22.7
5.5	13.8
3.9	6.5
2.8	0.0

Blaine 4280 cm2/g

* Source: St. Lawrence Cement

EXHIBIT 10
EVALUATION OF BLAST FURNACE SLAG
UNIT POWER CONSUMPTION FOR GRINDING

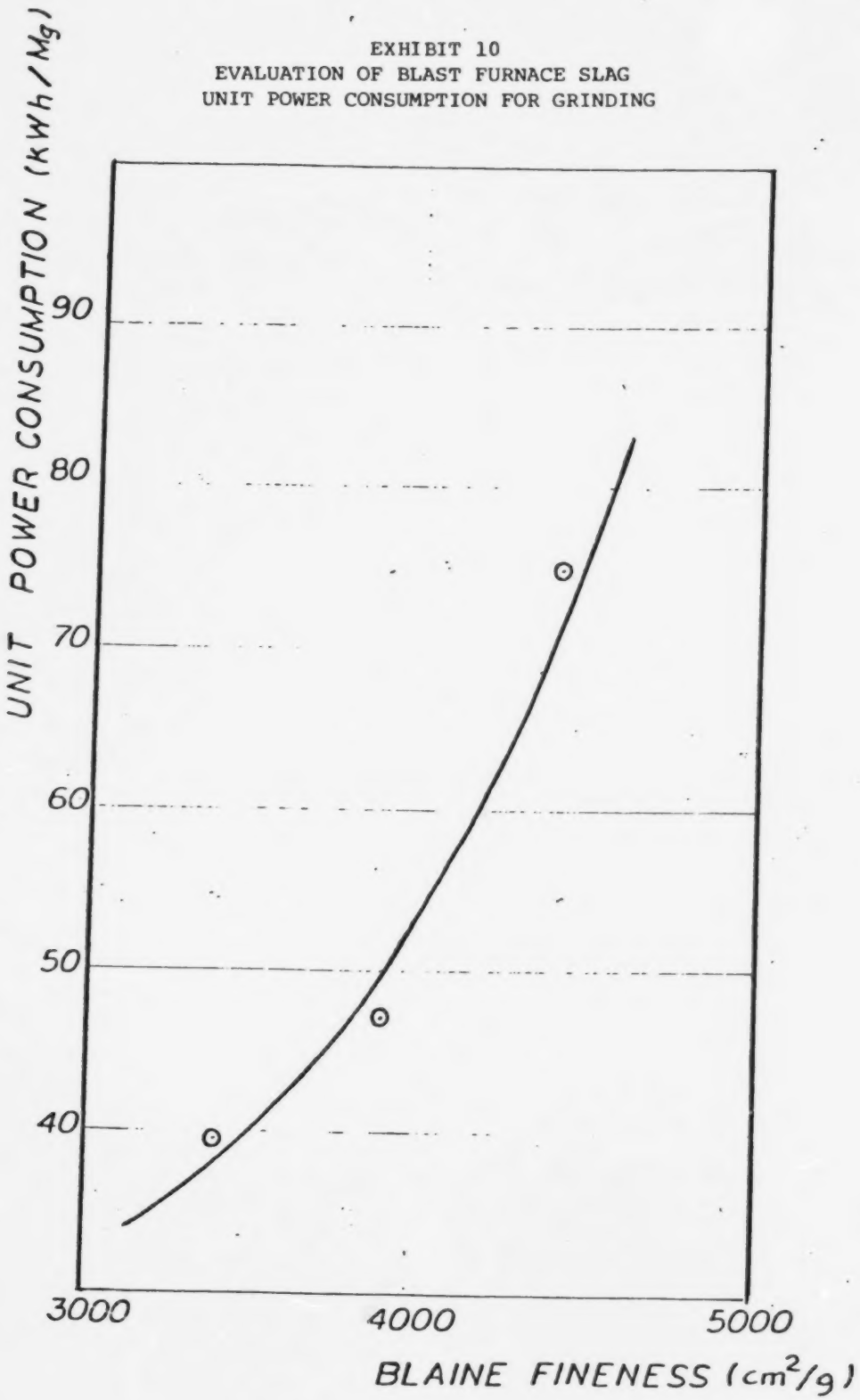
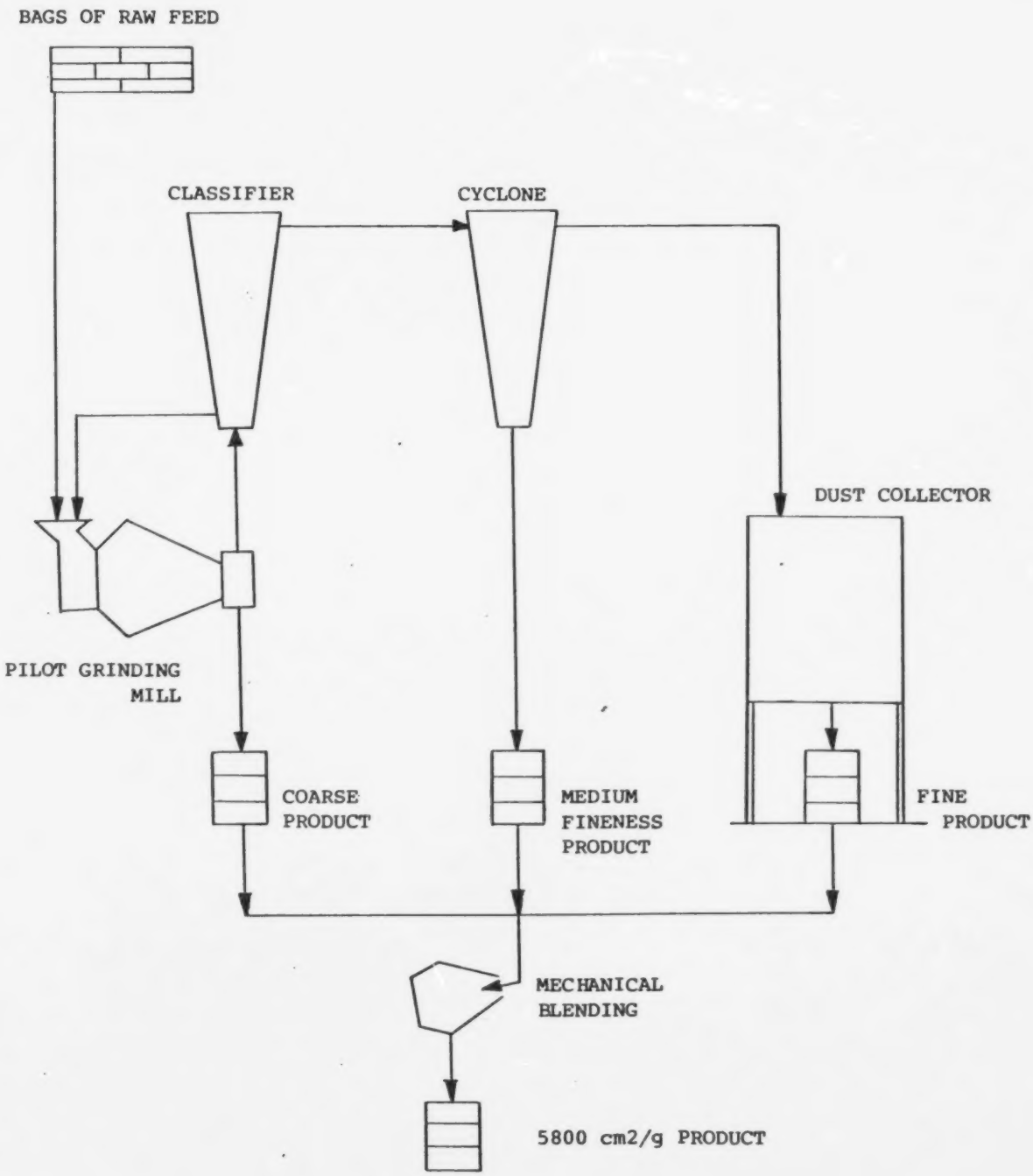
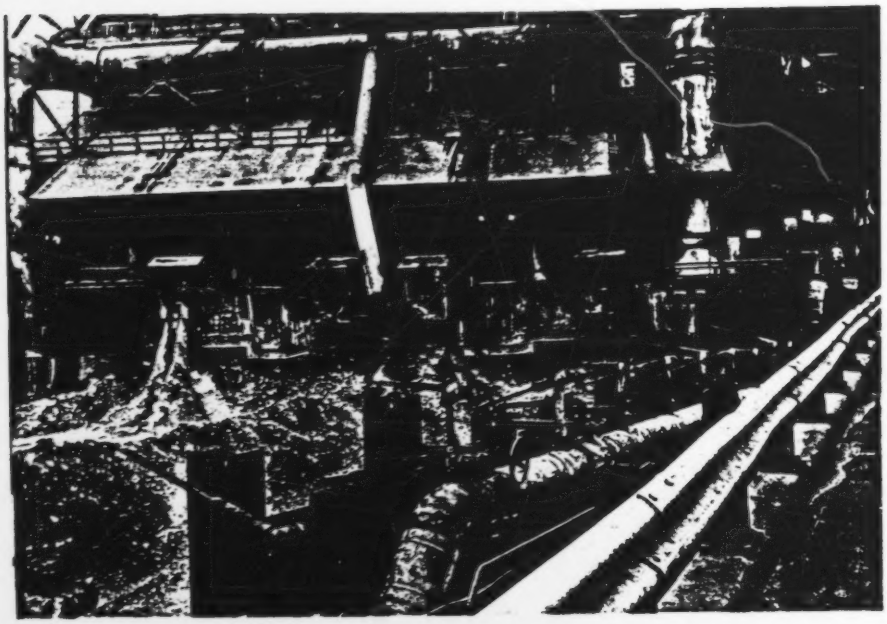


EXHIBIT 11
EVALUATION OF BLAST FURNACE SLAG
PILOT GRINDING MILL CIRCUIT SCHEMATIC

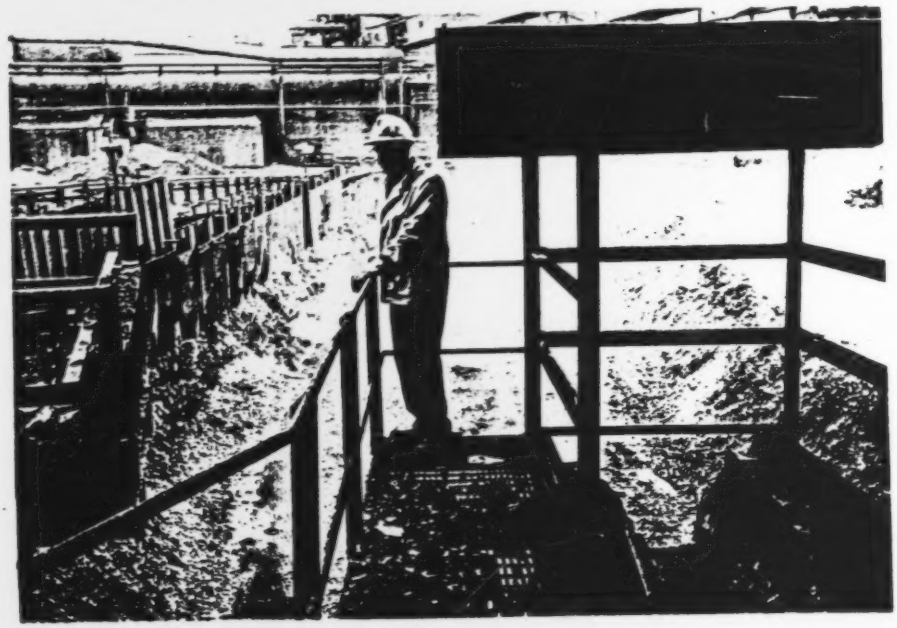


APPENDIX I

APPENDIX 1
GRANULATION EQUIPMENT SITE
JUNE 27, 1984



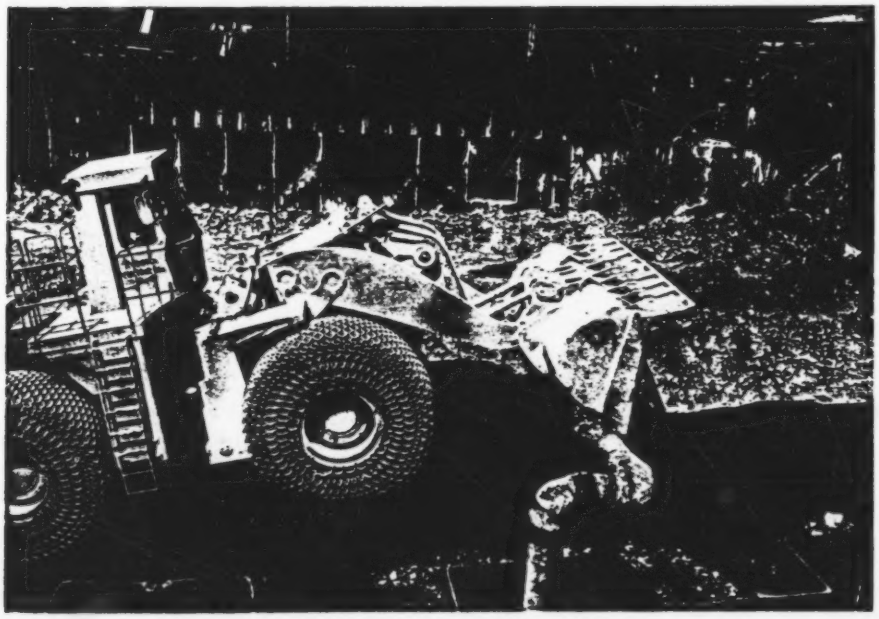
1. View of slag pits from outside Cast House showing four hot slag discharge runners, slag pit wall and slag spray nozzles.



2. View of slag pits from inside Cast House looking out along hot slag discharge runner. Slag pit on right contains hot slag. Slag pit on left has been cleaned. Steelworker in photo serves as size reference.

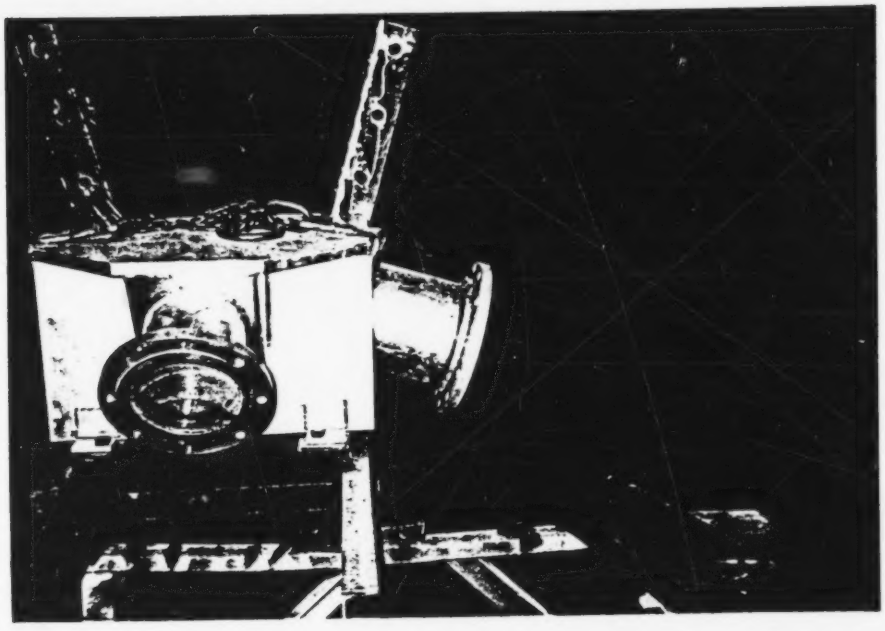
APPENDIX 1
EMBANKMENT FABRICATION
AUGUST 30, 1984

3. Waste sinter fines being dumped to form embankment

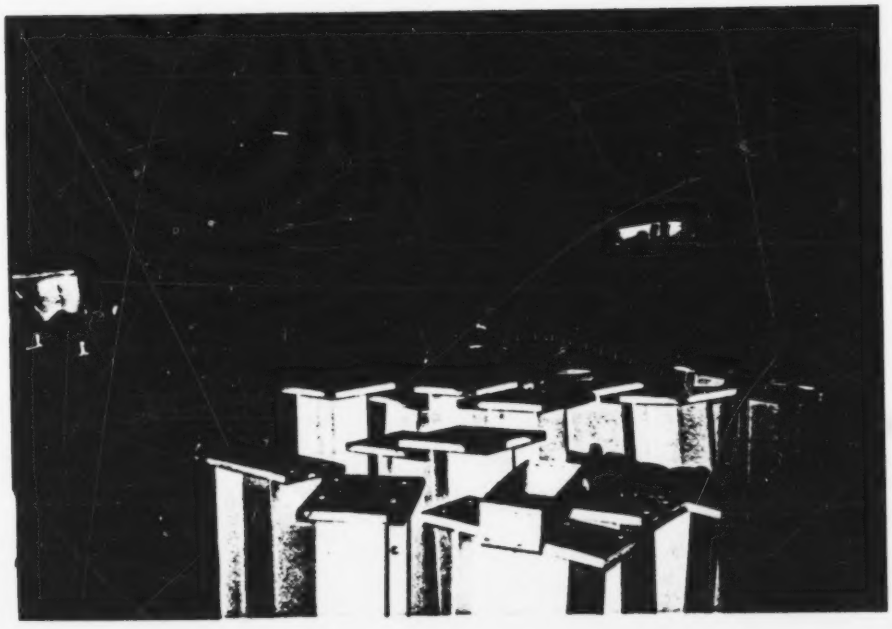


4. Embankment being leveled by Algoma Contractor's front-end loader

APPENDIX 1
GRANULATION EQUIPMENT COMPONENT PARTS IN
FABRICATION SHOP
OCTOBER 18, 1984

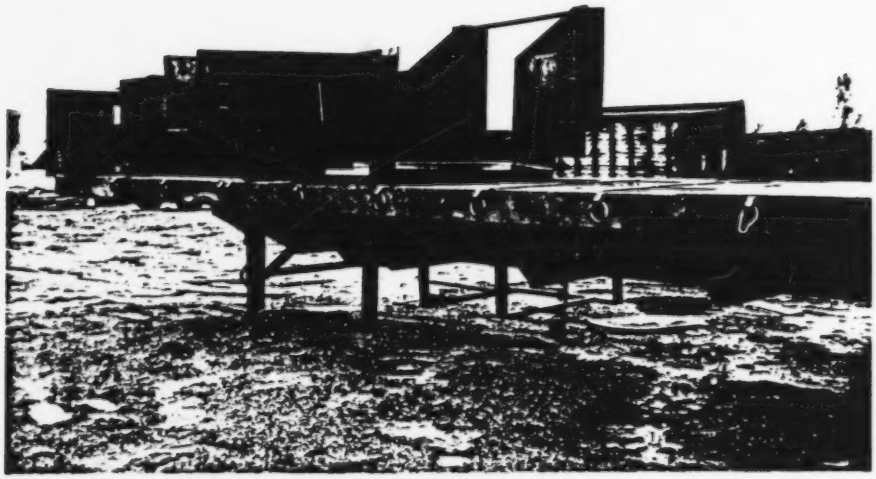


5. Paul Wurth blowing box



6. Cold runner (note Paul Wurth bloxing box is attached to near end)

APPENDIX 1
GRANULATION EQUIPMENT COMPONENT PARTS IN
FABRICATION SHOP
OCTOBER 18, 1984



7. Hot runner extension piece ready to be transported to site

APPENDIX 1
REFRACTORY INSTALLATION
OCTOBER 31, 1984

8. Employee spraying refractory mortar coating into hot runner

APPENDIX 1
INSTALLATION OF QUENCHING EQUIPMENT AT
ALGOMA STEEL'S #7 BLAST FURNACE
OCTOBER 31, 1984

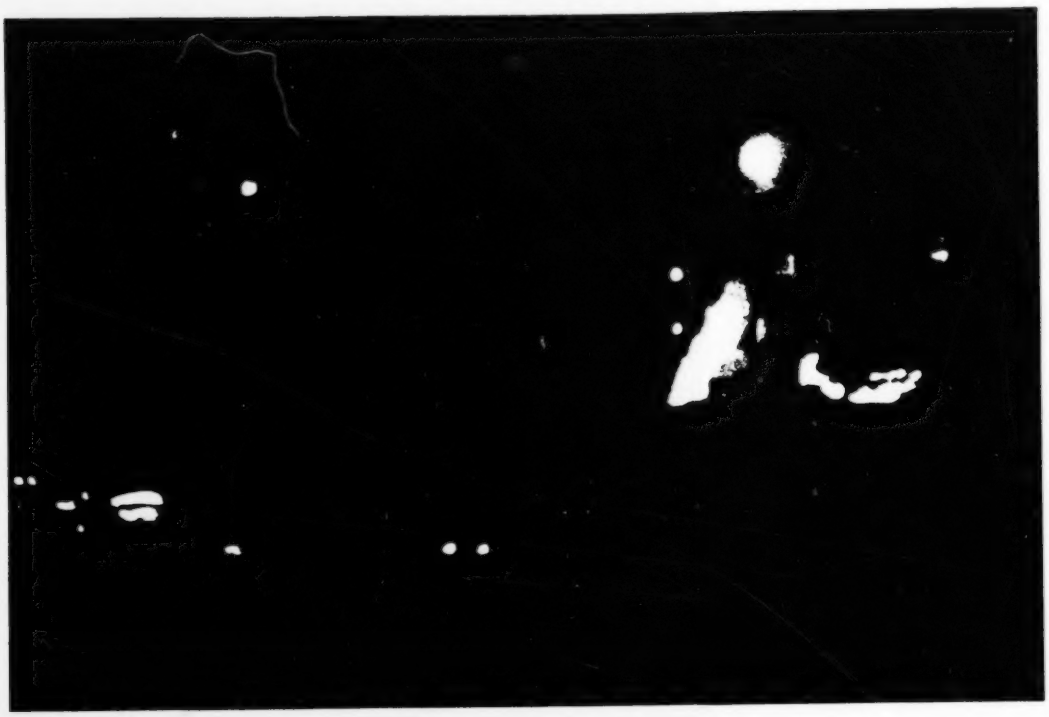
9. Lifting hot runner extension piece away from delivery truck in south slag pit

10. Hot runner being hoisted into place

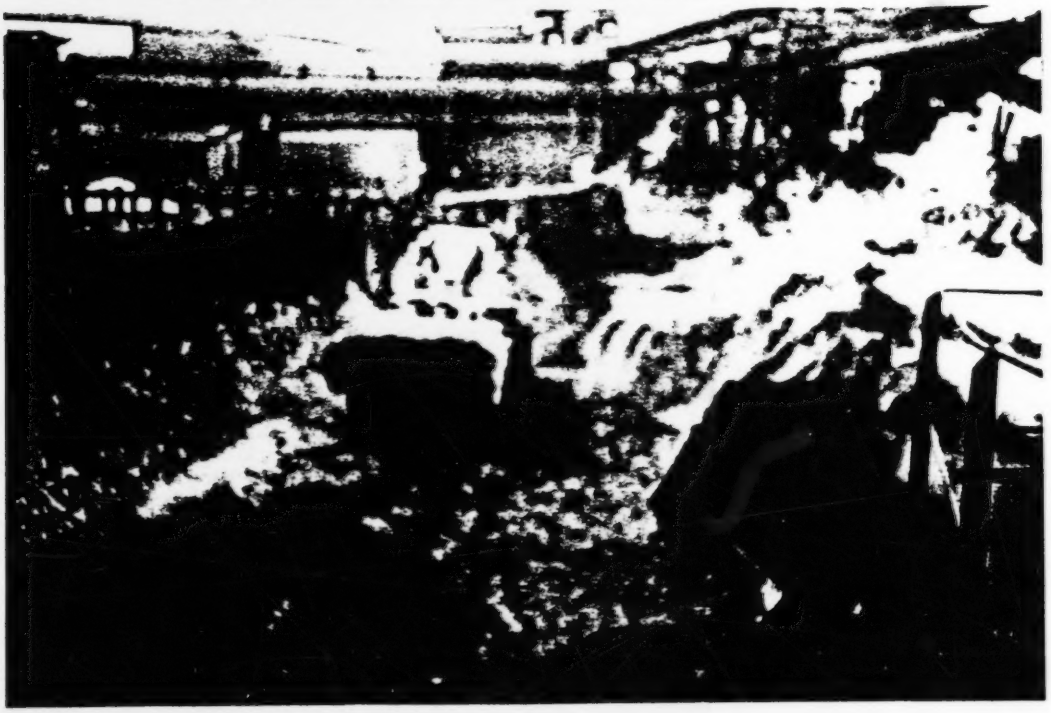
APPENDIX 1
INSTALLATION OF QUENCHING EQUIPMENT AT
ALGOMA STEEL'S #7 BLAST FURNACE
OCTOBER 31, 1984

11. Fitting the hot runner extension to the existing blast furnace hot runner

APPENDIX 1
SLAG GRANULATION
NOVEMBER 14, 1984

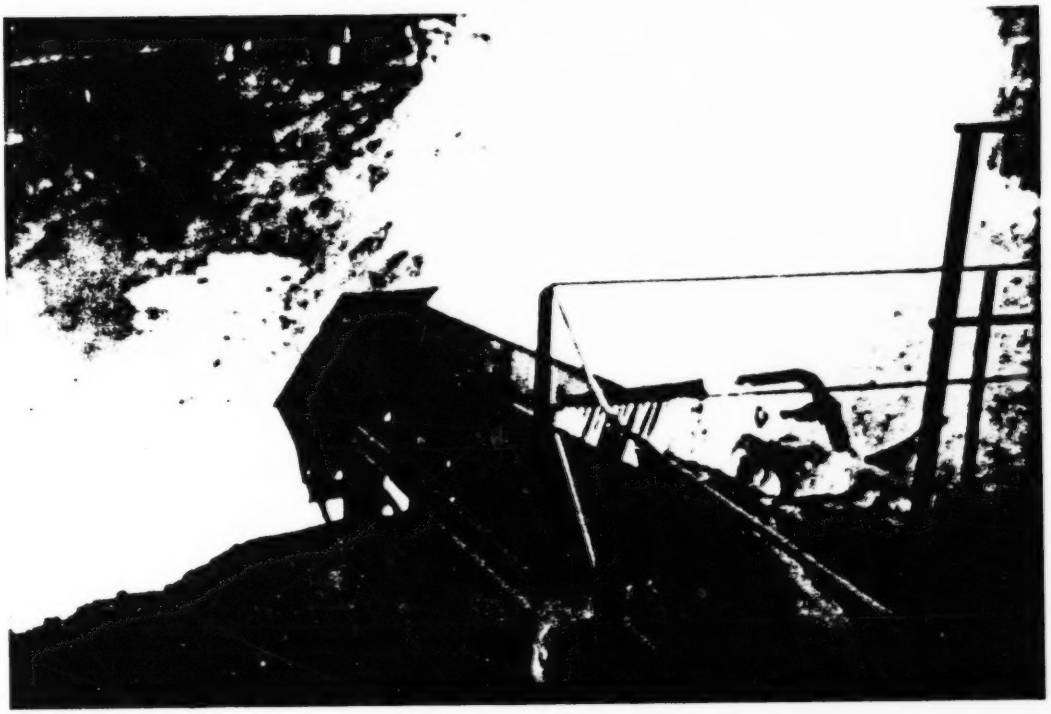


12. Last slag cast on north pit before granulation



13. Cleaning the south pit to receive granulated slag

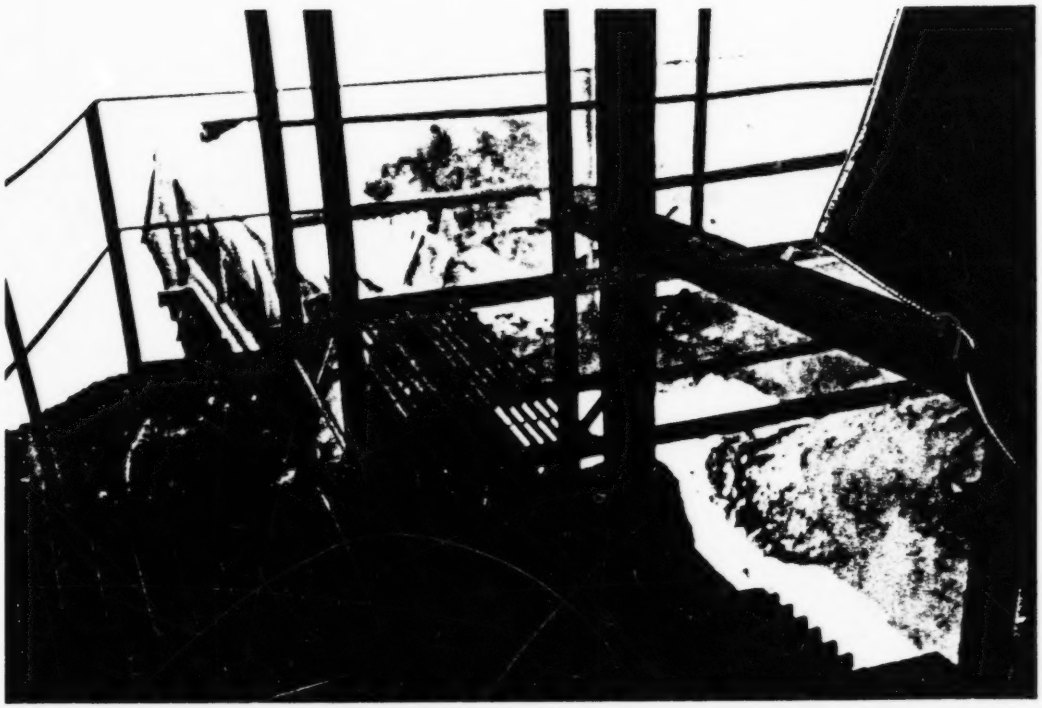
APPENDIX 1
SLAG GRANULATION
NOVEMBER 14, 1984



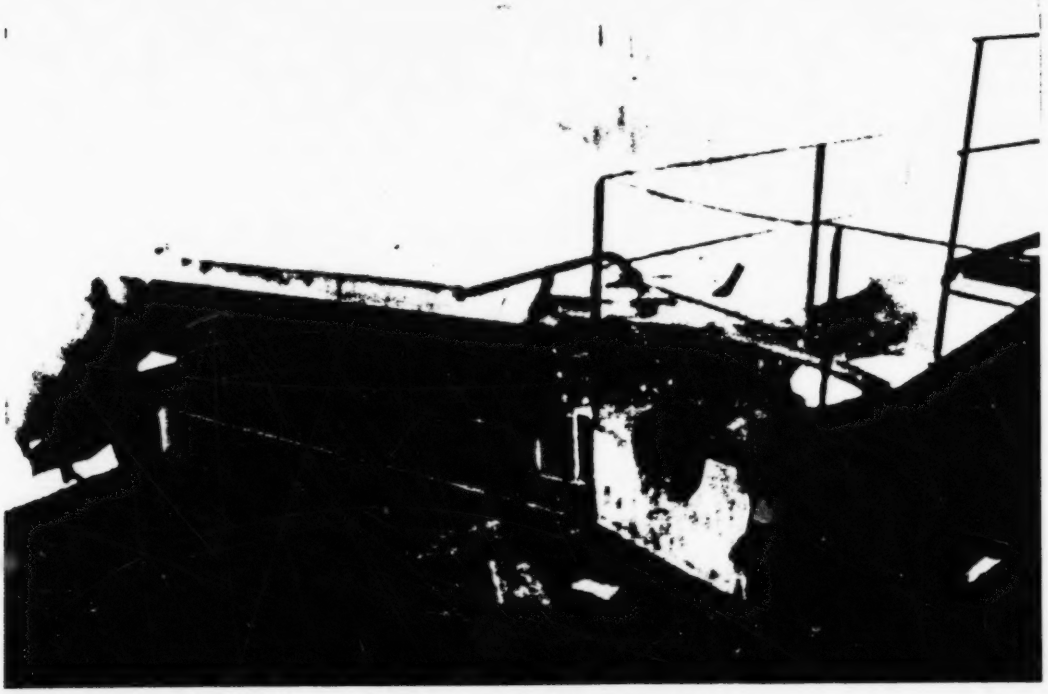
14. Testing water flow and preheating flow control orifice

15. Building the slag level control dam. Note flow control orifice

APPENDIX 1
SLAG GRANULATION
NOVEMBER 14, 1984

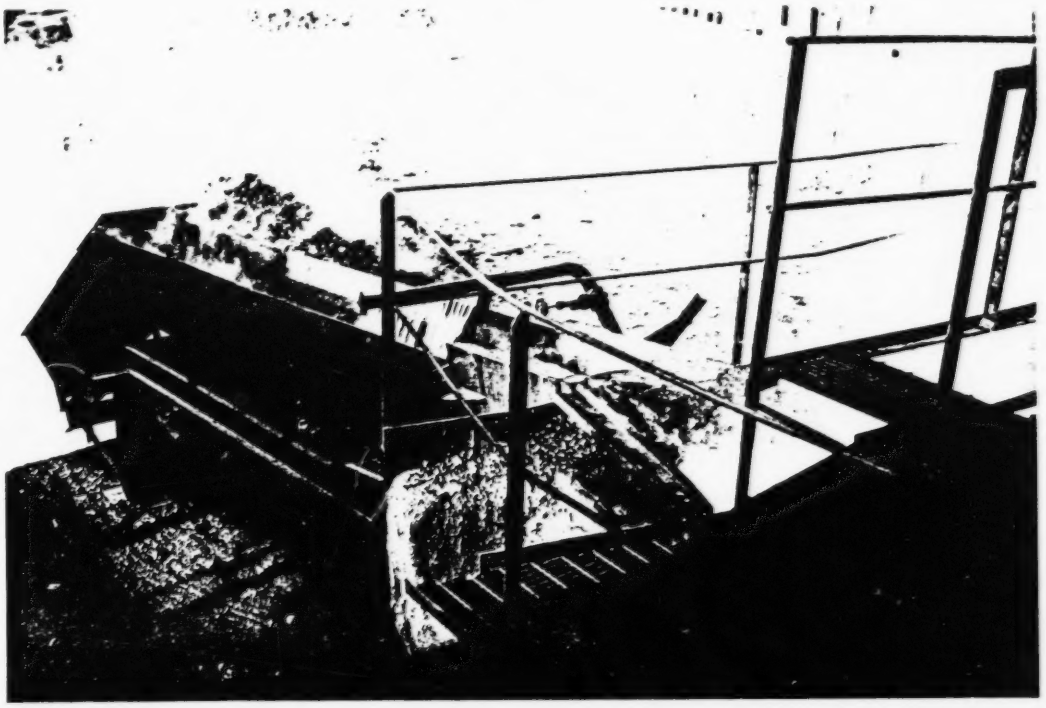


16. Granulation proceeding at full capacity

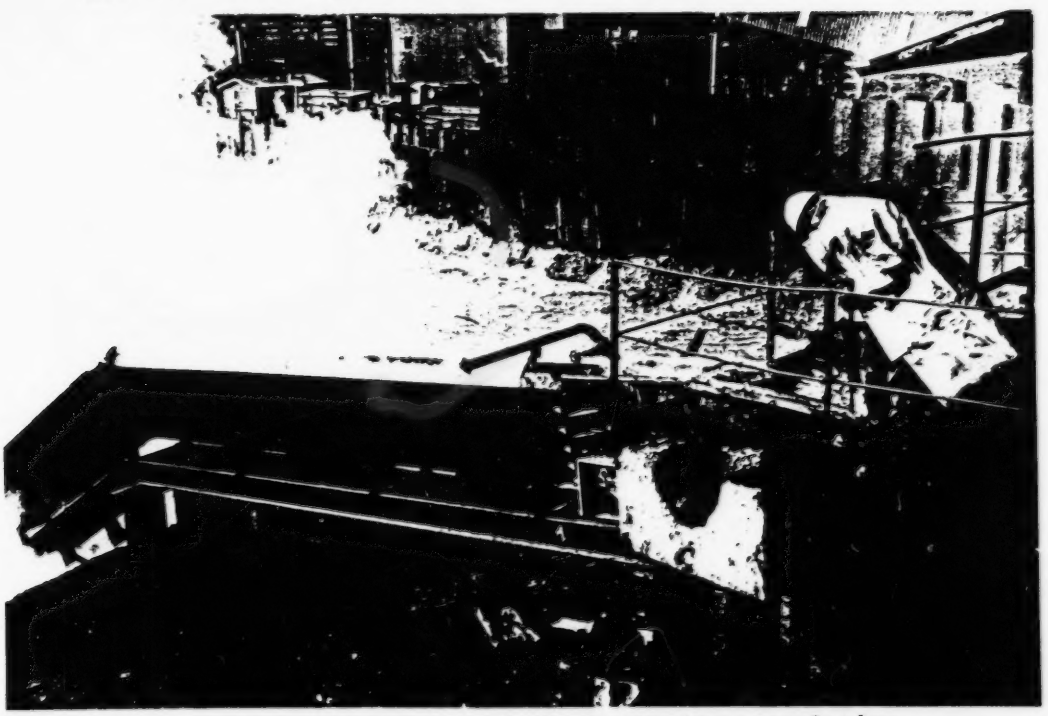


17. Granulation proceeding at full capacity

APPENDIX 1
SLAG GRANULATION
NOVEMBER 14, 1984

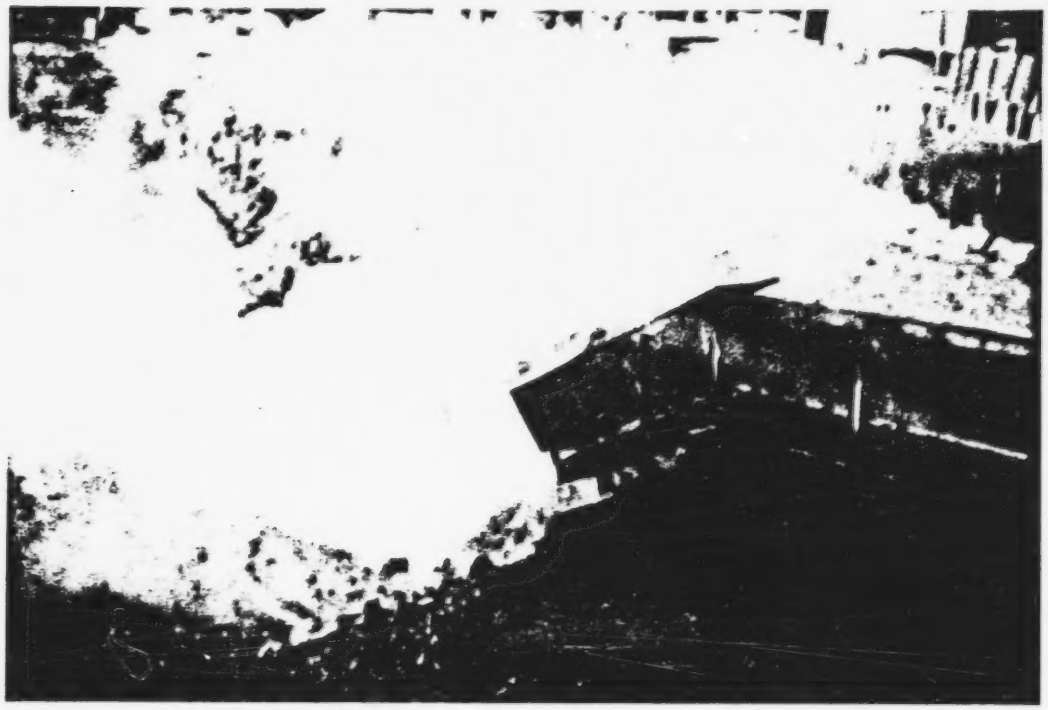


18. Granulation proceeding at full capacity

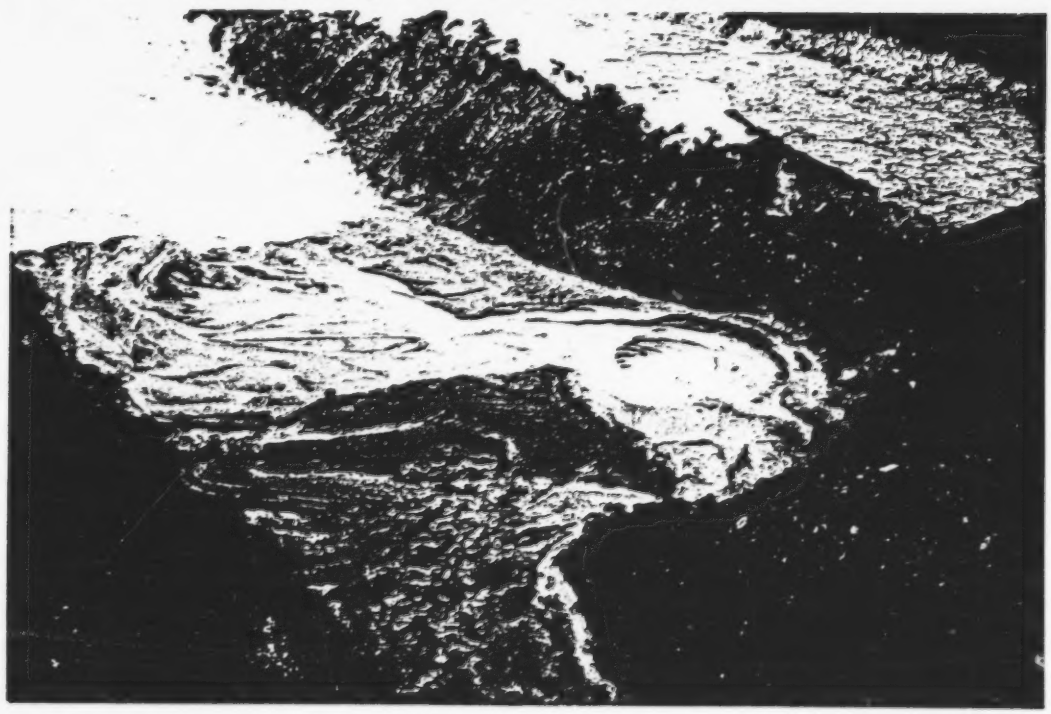


19. Trimming slag level control dam during granulation

APPENDIX 1
SLAG GRANULATION
NOVEMBER 14, 1984



20. Discharge of granulated slag into pit



21. Granulated slag pile in pit after granulation run. Note water separated in a pool at the foot of the pile.

APPENDIX 1
GRANULATED SLAG RECOVERY
NOVEMBER 14, 1984

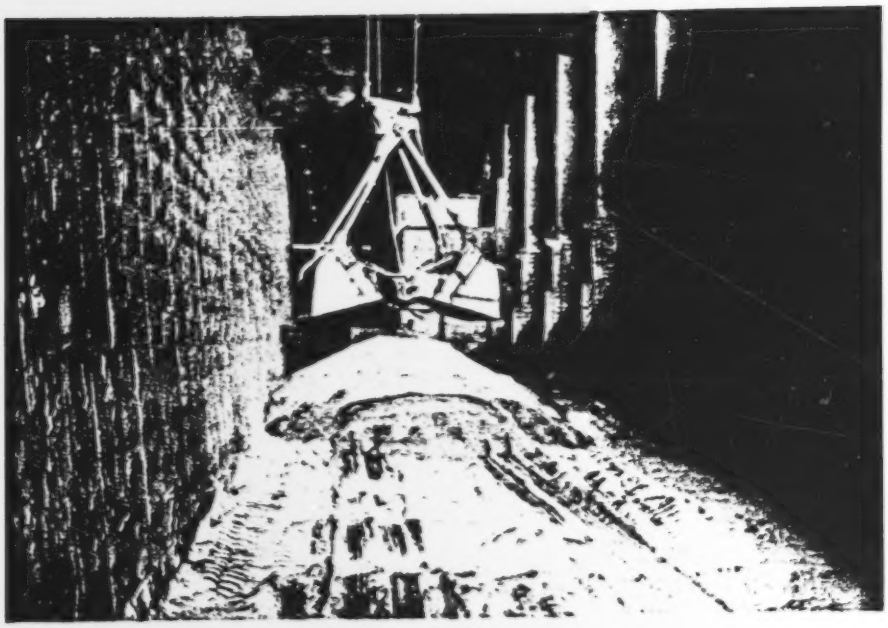
22. Granulated slag being recovered using a front-end loader and a dump truck in A.S.C. #7 south slag pit. (Note hot slag in north slag pit).

APPENDIX 1
SLAG GRINDING - ST. LAWRENCE CEMENT
NOVEMBER 30, 1984

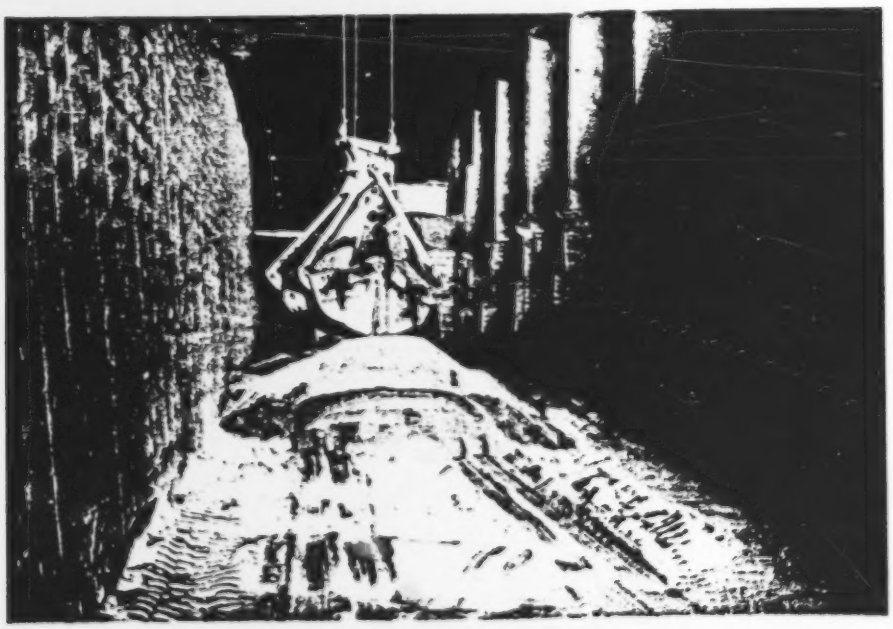
23. St. Lawrence cement storage hall

24. Unloading the granulated slag in the storage hall

APPENDIX 1
SLAG GRINDING - ST. LAWRENCE CEMENT
NOVEMBER 30, 1984

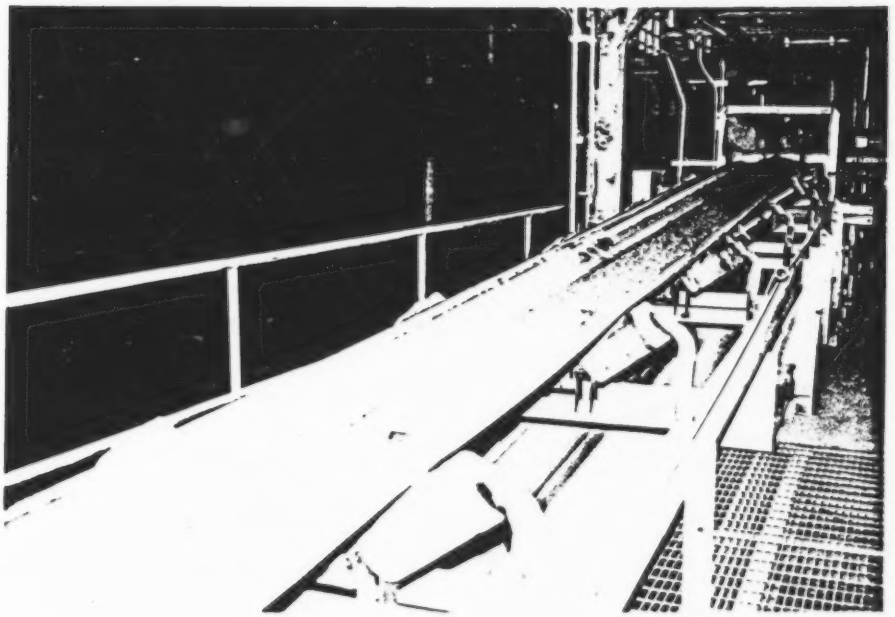


25. Handling the granulated slag with the clam shell crane

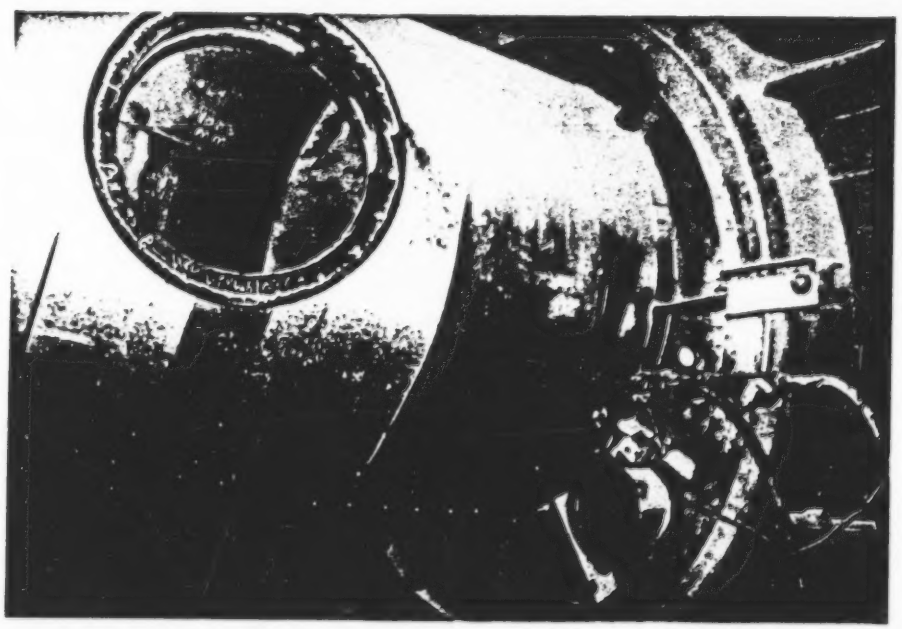


26. Handling the granulated slag with the clam shell crane

APPENDIX 1
SLAG GRINDING - ST. LAWRENCE CEMENT
NOVEMBER 30, 1984

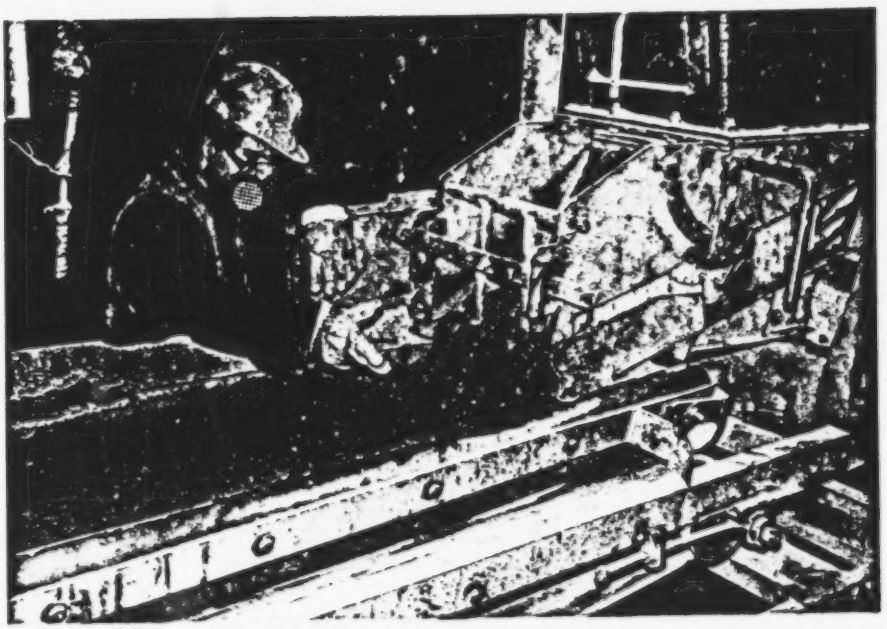


27. Feeding the wet slag into dryer

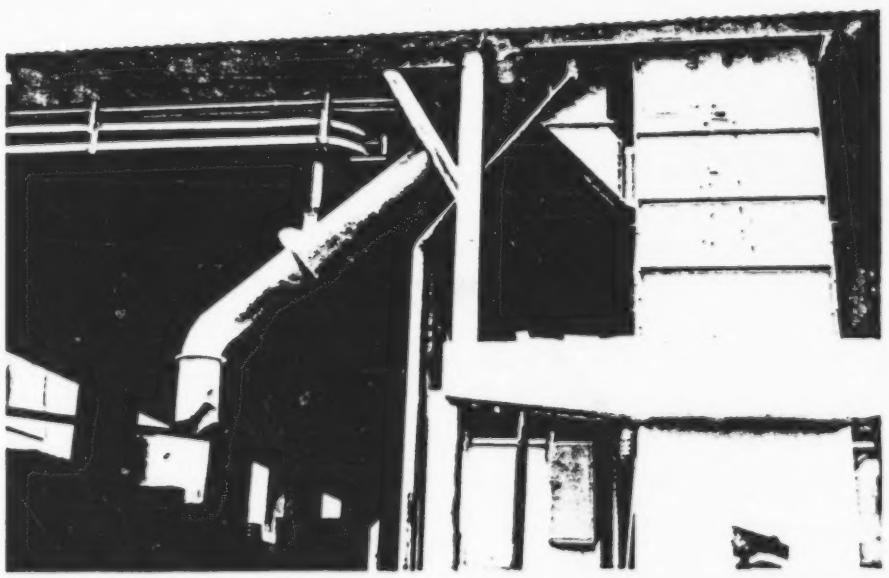


28. Temporary oil burner installed at dryer

APPENDIX 1
SLAG GRINDING - ST. LAWRENCE CEMENT
NOVEMBER 30, 1984

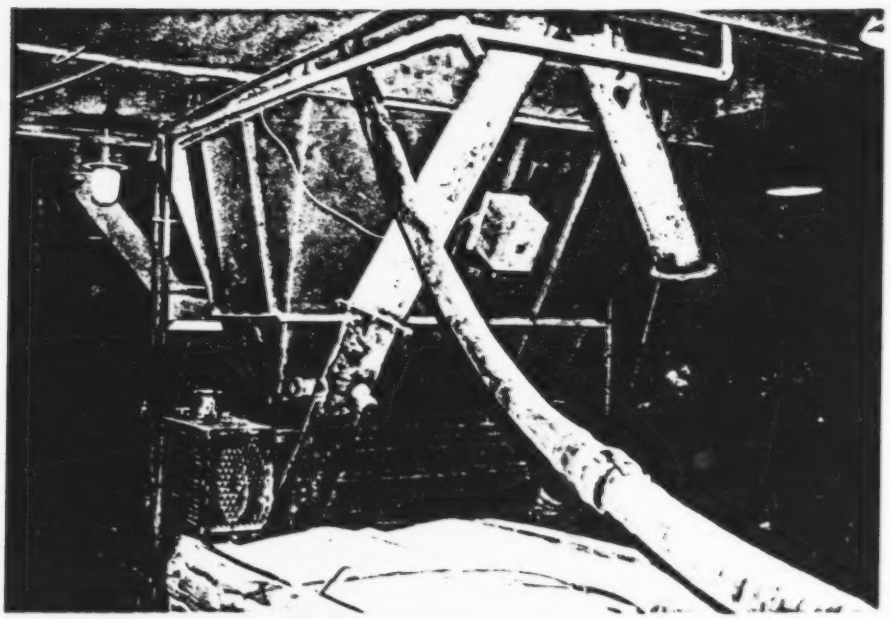


29. Mill feeder - checking for foreign particles

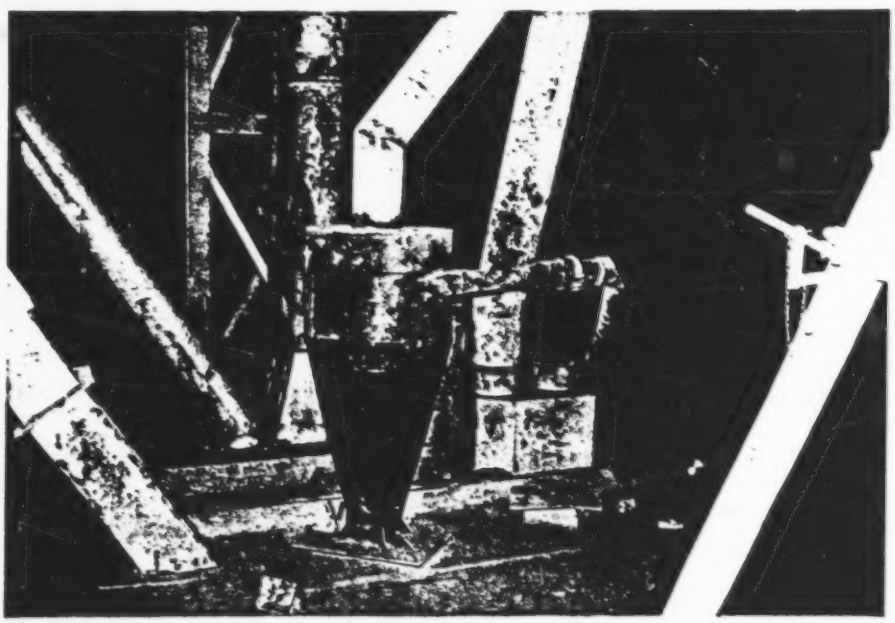


30. Chute to divert sample into tanker trucks

APPENDIX 1
SLAG GRINDING - ST. LAWRENCE CEMENT
NOVEMBER 30, 1984



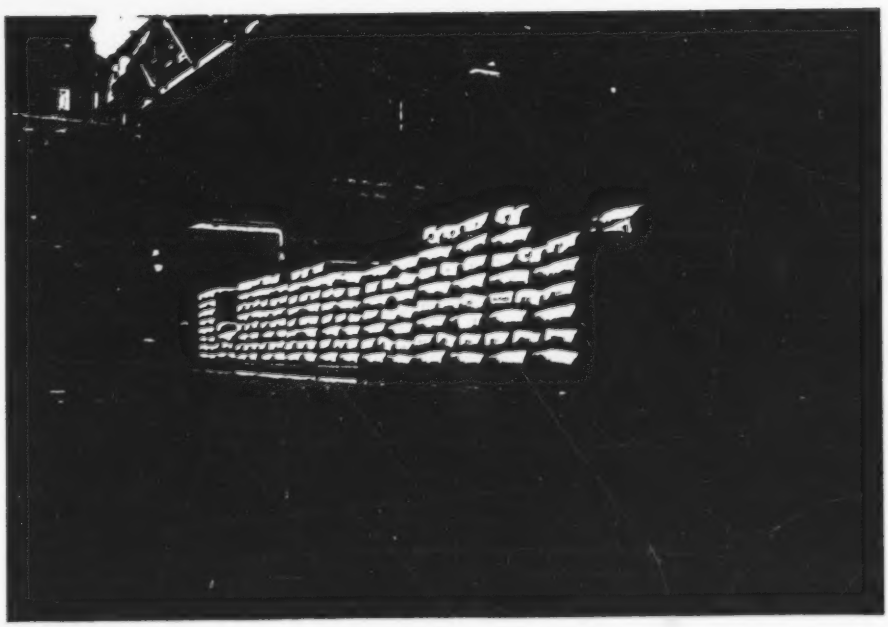
31. Hose to feed ground sample into packing machine



32. Alleviator installed to separate air from sample before discharging into packing machine hopper

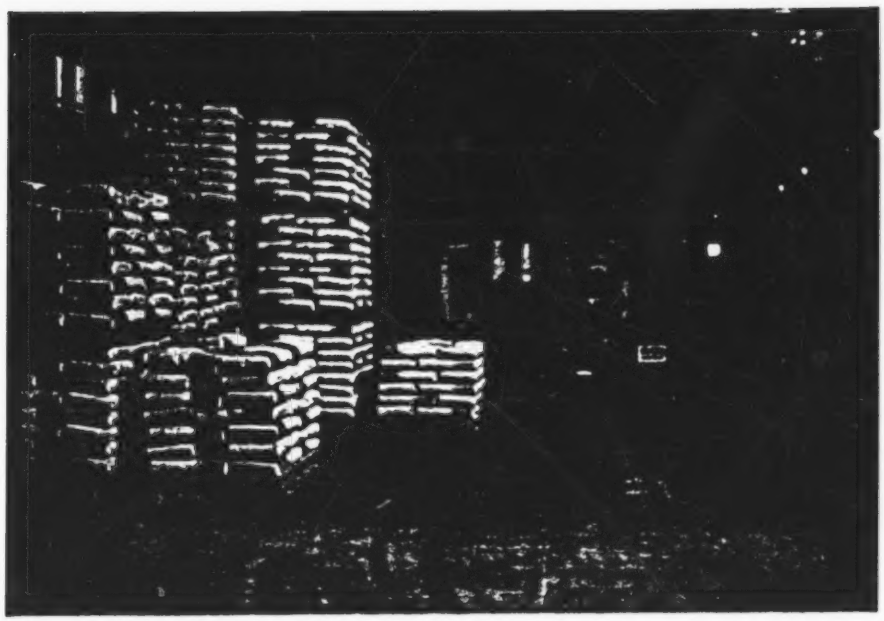
APPENDIX 1
SLAG GRINDING - ST. LAWRENCE CEMENT
NOVEMBER 30, 1984

33. Packing machine



34. Ground slag bagged and on pallets on a flat bed truck

APPENDIX 1
SLAG GRINDING - ST. LAWRENCE CEMENT
NOVEMBER 30, 1984



35. Storing bagged sample in kiln building to protect from weather

APPENDIX II

APPENDIX II

UNITS OF WEIGHTS AND MEASURES

The following units have been used in this report, and in general, the metric system has been used.

Length	- meters (m), millimeters (mm)
Mass	- Kilograms (kg), Megagrams (Mg) (1 Mg = 1 metric tonne)
Temperature	- Degrees Celsius
Power	- Kilowatts (kW)
Cement Fineness	- Blaine (cm2/g)